Federated Wireless, Inc.
4075 Wilson Boulevard
9th Floor
Arlington, VA 22203
www.federatedwireless.com

November 22, 2019

VIA ECFS
Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

RE: Notice of Ex Parte Presentation, *Unlicensed Use of the 6 GHz Band*, ET Docket No. 18-295.

Dear Ms. Dortch:

As a follow up to the October 29, 2019, meeting that representatives from Federated Wireless Inc. ("Federated Wireless") held with staff from the Wireless Telecommunications Bureau and the Office of Engineering and Technology, Federated Wireless submits the attached technical proposal regarding the use of an Automated Frequency Coordinator ("AFC") to enable new unlicensed services in the 6 GHz band as well as a recommended propagation model(s) to be used by AFCs.

Federated Wireless has developed and demonstrated a fully functional AFC prototype that will accelerate the introduction of a variety of unlicensed services, while ensuring protection of existing services, in the 6 GHz band. The AFC is essential to realize the potential of the 6 GHz band and its development will not delay entry of new services in the band. Federated Wireless notes that industry has coalesced around the need for an AFC for a wide variety of use cases, including both outdoor operations and operations with output power greater than 250 mW. Given this growing consensus and the ongoing work within industry to standardize AFC functionality, Federated Wireless asks that the Commission continue to build on this momentum by addressing the AFC in the upcoming 6 GHz order and by deciding a few key issues to assist industry in its efforts to reach agreement quickly on an AFC implementation framework.

While stakeholder consensus building and standardization is generally a time intensive activity, this task can be completed quickly and efficiently with direction from the Commission on important technical issues, such as the propagation model(s) to be used as a reference for AFC conformance testing. The propagation model loss estimate would be a component of a link budget calculation used to demonstrate compliance with specified interference protection criteria for incumbent services in the 6 GHz band. The propagation model could be independently tested to ensure that an AFC computes a path loss that is equal to or more conservative (i.e., smaller) than that calculated by the reference model. AFC conformance testing against this certification standard would then allow review of results and approval by the Commission through the existing OET equipment authorization process that includes use of authorized third-party laboratories for testing and black box conformance testing against a single certification standard.

Federated Wireless encourages the Commission to act expeditiously to make the 6 GHz band available for unlicensed use as broadly and quickly as possible and leverage the lessons learned in implementing other sharing regimes to ensure that the AFC in the 6 GHz band best meets the present and future needs of incumbents and newly authorized unlicensed users.

Respectfully submitted,

/s/ Jennifer M. McCarthy

Jennifer M. McCarthy
Vice President, Legal Advocacy
Federated Wireless, Inc.
4075 Wilson Boulevard, 9th Floor
Arlington, VA 22203

6 GHz Automated Frequency Coordinator Propagation Models

1 Introduction

As the Federal Communications Commission (FCC or the Commission) adopts rules to enable the introduction of new services in the 6 GHz band, including use of an Automated Frequency Coordinator (AFC) to ensure protection of incumbent services, it is recommended that the Commission identify propagation model(s) to be used as a reference for AFC conformance testing. The propagation model loss estimate would be a component of a link budget calculation used to demonstrate compliance with specified interference protection criteria (IPC). The propagation model could be independently tested, as in CBRS (WINNF-TS-0061, 2019), to ensure that an AFC under test computes a path loss that is equal to or more conservative (i.e., smaller) than that calculated by the reference model. AFC conformance testing against this certification standard would then allow review of results and approval by the Commission through the current Office of Engineering and Technology (OET) authorization process.

2 Motivation and Summary

Individual propagation models are generally tailored to certain morphologies (e.g., rural, urban, suburban), available geodata (e.g., terrain data, landcover categories), and scenarios of interest (e.g., short- vs. long-range, antenna heights). Hence, in practical applications that span a broad range of conditions, a "hybrid" model is needed to provide a general model that can be used for all transmitters and receivers of interest. For instance, CBRS (WINNF-TS-0112, 2019) uses a hybrid of extended HATA (EHATA) (TR-15-517, 2015) and Irregular Terrain Model (ITM) (TR82-100, 1982), where EHATA is used in short-range links in urban and suburban areas where clutter effects are prominent and ITM is too conservative given its limited incorporation of clutter losses.

Similarly, for 6 GHz incumbent protection, a hybrid propagation model that combines ITM, best suited for larger distances or rural environments, with WINNER II (WINNERII, 2007), appropriate for urban and suburban areas at close distances, is recommended. For clutter loss, ITM is augmented with International Telecommunications Union (ITU) – Radiocommunications (ITU-R) P.2108 (P.2108, 2017) for urban/suburban situations and ITU-R P.452 for other scenarios (P.452, 2015). It is noted that there is strong industry consensus on this choice of hybrid model for AFC calculations [(Erceg, 2019), (6USC, 2019), (Alliance, 2019), (RKF, 2018)]. For building entry loss (BEL), similar to [(RKF, 2018), (Alliance, 2019)], we would also apply ITU-R P.2109 (P.2109, 2019) on indoor-to-outdoor links.

ITM is a statistical model that is derived from and verified against extensive measurements (TN101, 1967, p. Annex V) and based on the electromagnetics theory, incorporating diffraction and troposcatter phenomena. ITM accurately models loss in rural areas and in other areas at distances greater than 1 km where terrain elevation, as opposed to man-made clutter, dominates the propagation loss. Point-to-Point Prediction mode (P2P) ITM (TR82-100, 1982), adopted by CBRS (WINNF-TS-0112, 2019) and with the availability of reference code from both CBRS-related WInnForum (SAS-WInnForum, n.d.) and National Telecommunications and Information Administration (NTIA) (ITS, n.d.), is proposed for AFC as the nuances of its preparatory modules/parameters have been extensively vetted by NTIA (ITS, n.d.), Department of Defense

(DoD), and various CBRS commercial entities of interest and all is included end-to-end in the WInnForum CBRS reference code (SAS-WInnForum, n.d.), which makes all the modules readily available.

WINNER II is commonly used by mobile carriers and has been extensively validated by measurements by experts in the field, while accounting for clutter loss for urban/suburban environments below *1* km. It distinguishes between Line-of-Sight (LoS) and Non-LoS (NLoS) conditions (WINNERII, 2007), important propagation phenomena for short distances in urban/suburban environments, where clutter as opposed just terrain elevation impacts propagation. While WINNER II includes clutter modeling inherently, ITM does not contain explicit clutter modeling. To account for clutter modeling above *1* km, ITU-R P2108, a statistical model for clutter loss modeling, is added for urban/suburban settings and ITU-R P.452 is used for other morphologies. ITU-R P.2108 and ITU-R P.452 methodologies are recommended to determine on which links clutter loss should be applied. In addition, building entry loss is another important propagation phenomena and ITU-R P.2109 provides a conservative statistical model to characterize building loss without resorting to hard-to-find information such as building material.

Table 1 summarizes the proposed 6 GHz hybrid model, where the first column depicts the chosen constituent models of the hybrid model, the second column represents the use-case of the constituent models, the third column illustrates the motivation to choose the constituent models on column 1, and the fourth column elaborates the dependencies of the constituent models in terms of various inputs and parameters necessary to run the model.

Table 1:Various propagation models and databases proposed for AFC operation.

	Use-case	**Usage Motive**	**Dependency**
P2P ITM	Propagation pathloss for: 1. Rural 2. Urban/Suburban at distances beyond *1* km	1. Vetted by regulatory bodies & commercial entities 2. Includes path elevation, refractivity, and atmospheric parameters 3. Available reference code. 4. Earth curvature 5. Verified against measurement	1. Elevation 2. Refractivity 3. Climate 4. Antenna heights 5. Frequency 6. Distance
WINNER II	Propagation pathloss for: 1. Urban/Suburban at distances below *1* km	Includes clutter modeling for urban/suburban settings at short distances	1. Antenna heights 2. Distance 3. Frequency
ITU-R P.2109	BEL	Includes an overall statistical and conservative BEL	1. Probability 2. Frequency 3. Elevation angle between RLAN device and incumbent

			4. RLAN device category (indoor/outdoor)
ITU-R P.2108	Propagation clutter loss for: 1. Urban/Suburban beyond *1* km	1. Provides additional clutter to pathloss in urban/suburban settings 2. Well-documented by ITU	1. Distance 2. Antenna heights 3. Nominal clutter heights 4. Land cover
ITU-R P.452	Propagation clutter loss for: 1. Rural	1. Provides additional clutter to pathloss due to rural man-made clutter and well-documented by ITU	1. Nominal clutter height and distance 2. Distance 3. Frequency 4. Land cover 5. Antenna height
Elevation	CBRS* *1* asec** DB adopted from USGS† Seamless 3DEP*** DEM†††	1. Vetted by regulatory bodies & commercial entities 2. Available reference code 3. Open source public DB	Coordinate System
Land Cover	CBRS *1* asec adopted from NLCD2011††	1. Vetted by regulatory bodies & commercial entities 2. Available reference code 3. Open source public DB	Coordinate System
*CBRS: Citizen Broadband Radio Services ** asec: Arc second *** 3DEP: 3D Elevation Program	†USGS: United States Geological Survey ††NLCD: National Land Cover Database ††† DEM: Digital Elevation Model.		

3 Preparatory Computation

AFC computations require geodesic calculations, elevation evaluation, and landcover determination as explained in subsections 3.1, 3.2, and 3.3 respectively.

3.1 Geodesic Calculations

Inverse Vincenty and Forward Vincenty methods (Vincenty, 1975), following CBRS-adopted procedures (SAS-WInnForum, n.d.), are proposed for the implementation of geodesic calculations yielding the distance and azimuth between points, the great circle path and its point coordinates, and the points at a given distance and azimuth from a starting location. These CBRS procedures use World Geodesic System (WGS) 84, (WGS84), as the reference coordinate system (WGA, 2012).

3.2 Terrain Elevation

The terrain profile, defined herein as the AMSL elevation of the great circle coordinates along the path between an RLAN device and an incumbent receiver antenna, is needed to compute P2P ITM pathloss. The computation of this profile requires the use of an elevation DB, preferably a DEM DB. For this purpose, we suggest CBRS DEM (SAS-Data, n.d.) in view of its covering the entire

Unites States and parts of Canada and Mexico. This DB combines several opensource USGS 3DEP DBs covering entire Alaska, Conterminous U.S. (CONUS), Hawaii, and Guam as 1 deg $\times$ 1 deg tiles. Great circle coordinate and elevation calculations should then be done according to the procedures for CBRS as implemented in WInnForum git repository (SAS-WInnForum, n.d.).

3.3 Landcover Data

Opensource landcover data, referred to as NLCD, for CONUS, Alaska, and certain territories of the United States, was created by WInnForum CBRS processing of Multi-Resolution Land Characteristics (MRLC) consortium NLCD2011 DB (SAS-Data, n.d.) with extraction methodologies available in the WInnForum CBRS reference code (SAS-WInnForum, n.d.). The extraction of landcover of an RLAN device location is done according to the computations in the CBRS WInnForum implementation github repository (SAS-WInnForum, n.d.) and CBRS WInnForum landcover data github repository (SAS-Data, n.d.). The mapping from landcover to environment, *LandCat*, is provided in Table 2.

Table 2: Mapping Landcover to environment.

Environment	**Landcover**
Urban	*23*, *24*
Suburban	*22*
Deciduous	*41*, *43*, *90*
Coniferous	*42*
Rural	Other

4 Propagation Pathloss Model Details

All pathloss computations explained in this document are performed at the lower boundary of the 6 GHz band, 5.925 GHz, as it proves most conservative in incumbent protection and is within the range of all the propagation models in Table 1. Furthermore, all geodesic calculations, as explained in section 3.1, are implemented according to the WInnForum github repository for CBRS (SAS-WInnForum, n.d.).

4.1 Irregular Terrain Model

P2P ITM relies on the terrain profile, RLAN device and incumbent receiver antenna Above Ground Level (AGL) heights, path surface refractivity (TR82-100, 1982), and path climate (TR82-100, 1982). Computation of path surface refractivity and path climate are done according to the procedures devised in the WInnForum github repository (SAS-WInnForum, n.d.), whereas the geodesic and terrain profile computations are described in Sections 3.1 and 3.2 respectively. Following the CBRS incumbent protection methodology (WINNF-TS-0112, 2019), the mean of propagation loss from P2P ITM is used.

4.2 WINNER II Model.

WINNER II (WINNERII, 2007) produces pathloss as a function of the RLAN device and incumbent receiver antenna AGL height, great circle distance, d, between the RLAN device and incumbent receiver, and the environment (urban/suburban). The urban environment relies on scenario C2 (WINNERII, 2007) of WINNER II and suburban setting is based on scenario C1 (WINNERII, 2007), where both scenarios generate a break point d_{bp} for which LoS pathloss based on d is computed, then, NLoS loss is calculated, and, finally, both LoS and NLoS pathloss values are probabilistically weighted and added together to yield in the total composite pathloss. The probabilistic weighted addition is due to the fact that AFC may know not if the RLAN device incumbent path is indeed LoS or NLoS. The determination of environment, *LandCat*, is done by mapping the landcover at RLAN location to various environments, including urban and suburban for WINNER II purposes, as explained in section 3.3.

4.3 Building Entry Loss

BEL is computed using the methodology given in ITU-R P.2109 (P.2109, 2019) for traditional buildings. While ITU-R P.2109 provides models for both traditional and thermally efficient buildings, an AFC may not have knowledge of the building type the RLAN device is inside, so the more conservative traditional building model is proposed. Furthermore, the model has a statistical parameter and we use the mean loss for the AFC operation. The application of ITU-R P.2109 requires the path elevation angle, for this we propose using the elevation angle between the RLAN device and the incumbent receiver antenna, whose height and location is determined from FCC databases.

4.4 Clutter Loss

Given that ITM does not explicitly model propagation losses due to man-made clutter [(TR82-100, 1982), (TN101, 1967)], an additional propagation clutter loss from ITU-R P.2108 (P.2108, 2017) is proposed, where the mean value is applied, as explained below, for urban/suburban environments and ITU-R P.452 (P.452, 2015) otherwise. While ITU-R P.2108 (Equations 3-5 in (P.2108, 2017)) provides a cumulative distribution function (cdf) for the clutter loss (Figure 1), a proper application of this distribution conservatively protecting the incumbent receivers is essential. In particular, median clutter loss is not conservative enough to account for worst case effects. A conservative compromise would be applying the mean value (*27.0162* dB at *5.925* GHz), for which a constant loss at *1* km will be used for all distances. Moreover, the ITU-R P.2108 loss must only be applied when the interferer is within the clutter, represented by the nominal clutter height h_a, as depicted in Figure 2 and Algorithm (1), at *10* or *15* m for suburban and urban environment (P.2108, 2017).

Rural clutter comes from ITU-R P.452 under conditions in Algorithm (1) (P.452, 2015), also depicted in Figure 2. The parameters of ITU-R P452 are nominal clutter height h_k and nominal clutter distance to receiver, i.e., the incumbent, d_k with values given in Figure 2 as well as in Algorithm (1) for coniferous, deciduous, and rural settings (P.452, 2015), whose determination relies on mapping the RLAN device location landcover code to deciduous/coniferous/generic-rural as explained in section 3.3. The conditions on when to apply ITU-R P.452 clutter loss are i) RLAN device-to-incumbent receiver distance $d > 10\ d_k$, and ii) RLAN device AGL antenna $h_{\text{RLAN,AGL}} < h_k$, and iii) the slope of the line connecting the RLAN device to incumbent receiver, a, be less than that of RLAN device to nominal clutter height, b (P.452, 2015) .

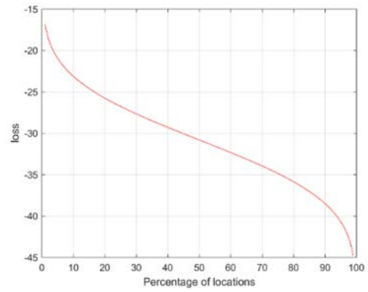

Figure 1: ITU-R P.2108 clutter loss cdf.

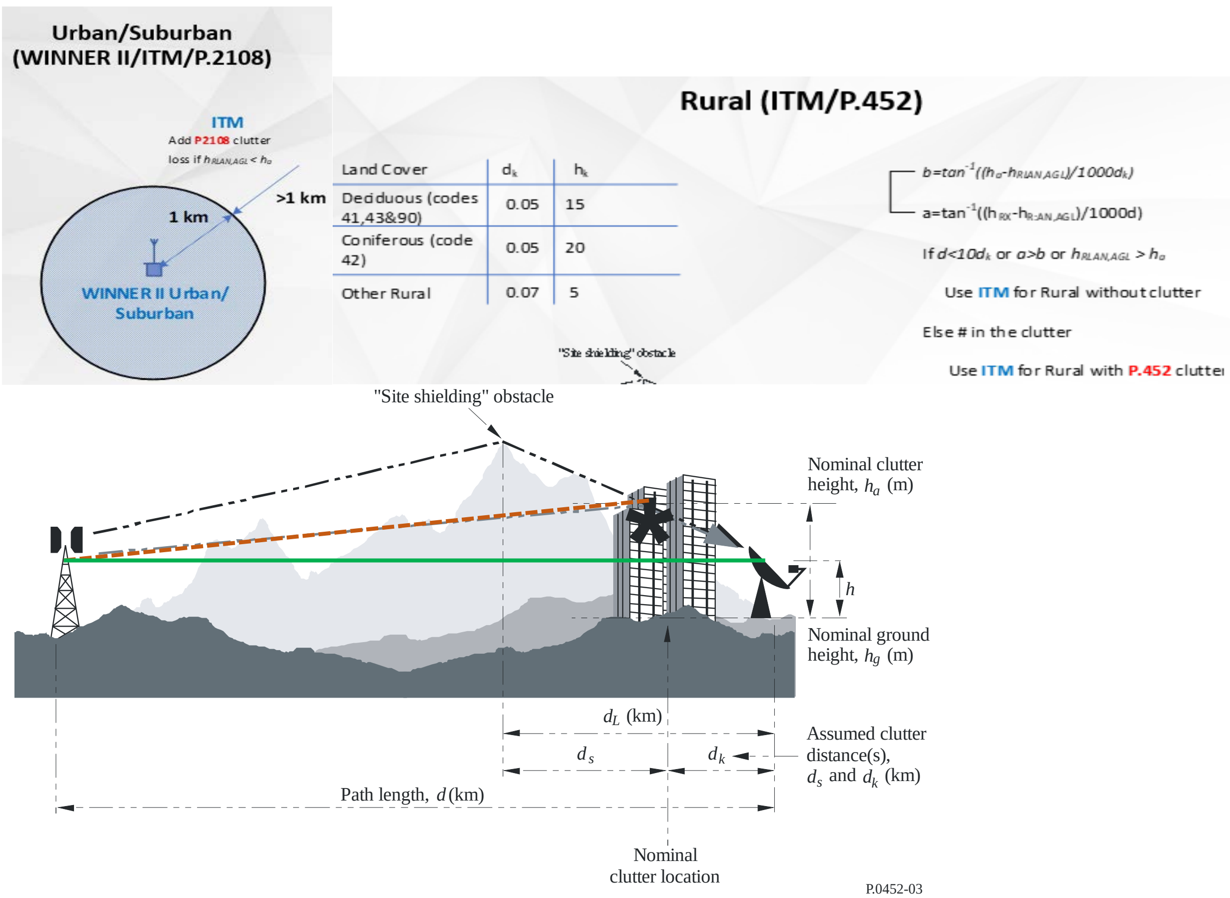

Figure 2: Example of parameters of ITU-R P.452, as well as clutter/pathloss application.

4.5 Discontinuity Between Constituent Models

One of the challenges with adopting a hybrid model is the transition between its constituent models. For the proposed 6 GHz hybrid model, WINNER II and ITM-plus-clutter-loss at *1* km can mismatch by more than *30* dB as they use different modeling methodologies. The mismatch depends on the link terrain elevation variation and the environment (urban, suburban). For instance, large terrain irregularity results in WINNER II yielding a smaller path loss than ITM-plus-clutter estimates, whereas ITM-plus-clutter yields less loss in an urban flat scenario. Allowing the discontinuity at *1* km would fail to leverage the advantages each model offers in estimating the loss around *1* km. In contrast, avoiding the discontinuity by choosing the model giving the smallest loss at each distance could overestimate the interference by *30* dB or more, resulting in inefficient spectrum utilization.

Therefore, to optimize use of the two models, it is proposed to interpolate them to yield a smooth transition around *1* km. Illustrated in subsection 4.5.1, the proposed method i) applies to "urban and suburban" environments, ii) suggests an intermediate distance of $d_{intermediate}$, which depends on the terrain profile and is less than *1* km, before which WINNER II is leveraged, iii) recommends a *1* km threshold after which ITM-plus-clutter-loss is applied, and iv) adopts a linear interpolation of the WINNER II loss at $d_{intermediate}$ and ITM-plus-clutter-loss at *1* km for between the two distance thresholds.

4.5.1 Methodology to Surmount Discontinuity at 1 km

Applying WINNER II/(ITM-plus-clutter-loss) before/after *1* km can cause discontinuity at *1* km. To eliminate the discontinuity, we propose using $d_{intermediate}$ before which we apply WINNER II. Post *1* km, we retain the application of ITM-plus-clutter-loss $L_{ITM}^{C}(d)$ = ITM + P.2108 (*d* denotes RLAN device-to-incumbent receiver distance in km). For instance, we choose $d_{intermediate}$ = *500 m* and present below an interpolation methodology using this distance.For distances between *500* m and *1* km, we linearly interpolate between the WINNER II pathloss at *500* m, L_{W2} *(d=0.5 km)*, and ITM-plus-clutter-loss at 1 km, $L_{ITM}^{C}(d = 1\ km)$, to obtain the end-to-end path loss at distance *d* between the RLAN and the receiver, *L(d)*. This is shown in Figure 3 and the interpolation is also presented in equation (1). This methodology is akin to the CBRS discontinuity treatment at 1 km and has been vetted by NTIA (TR15-517, 2015).

$$\begin{aligned} L(d) = L_{ITM}^{C}(1) + \frac{L_{ITM}^{C}(1) - L_{W2}(0.5)}{log_{10}(1) - log_{10}(0.5)}(log_{10}(d) - log_{10}(1)) \\ = L_{ITM}^{C}(1) + \frac{L_{ITM}^{C}(1) - L_{W2}(0.5)}{-log_{10}(0.5)} log_{10}(d) \\ = L_{ITM}^{C}(1) + \frac{L_{ITM}^{C}(1) - L_{W2}(0.5)}{log_{10}(2)} log_{10}(d) \xrightarrow{yields} L(d) \\ = L_{ITM}^{C}(1) + (L_{ITM}^{C}(1) - L_{W2}(0.5)) log_{2}(d), \quad ; 0.5 < d < 1 \end{aligned} \tag{1}$$

To check whether the breakpoints do not portray any discontinuity for equation (1), we check the two break points of *500* m and *1* km below.

$$L(1) = L_{ITM}^{C}(1) + \left(L_{ITM}^{C}(1) - L_{W2}(0.5)\right) log_{2}(1) = L_{ITM}^{C}(1)$$
$$L(0.5) = L_{ITM}^{C}(1) + \left(L_{ITM}^{C}(1) - L_{W2}(0.5)\right) log_{2}(0.5) = L_{W2}(0.5)$$

We can represent the propagation model before *500* m, after *1* km (until *2000* km, recommended limit for ITM (TR82-100, 1982)), and in between as equation (22) where *U(x)* is the step function, *0* for *x < 0* and *1* otherwise.

$$L(d) = \Big[L_{W2}(d)U(0.5-d) + L_{ITM}^{C}(d)U(d-1) + L_{ITM}^{C}(1) + \Big(L_{ITM}^{C}(1) - L_{W2}(0.5)\Big)log_2(d)\big(U(d-0.5) - U(d-1)\big)\Big]\big(U(d) - U(d-2000)\big) \quad (2)$$

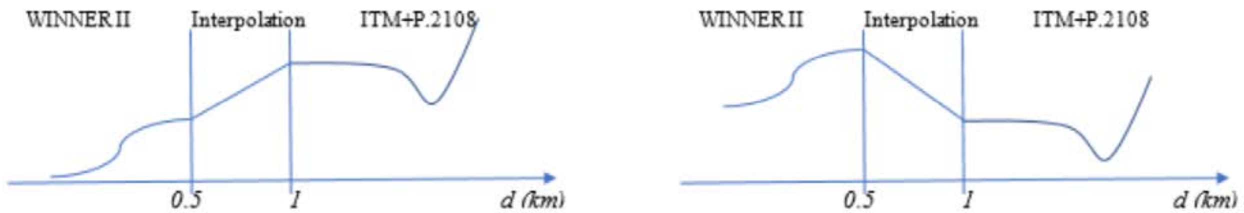

Figure 3: Before/After *0.5*/*1* km, we apply WINNER II / ITM-plus-clutter-loss. In between, we interpolate WINNER II at *0.5* km with ITM-plus-clutter-loss at *1* km.

5 Hybrid Propagation Model

Algorithm 1 pseudocode details the proposed hybrid propagation model, whose pathloss, clutter loss, BEL, and terrain elevation and landcover databases and procedural components are summarized in Table 1 and elaborated in sections 3 and 4.

Algorithm 1 Computing propagation pathloss, BEL, and clutter loss for AFC.
Compute RLAN device location land category "LandCat" (section 3.3).
Select $d_{intermediate}$.
IF LandCat==Urban or LandCat==Suburban
    IF RLAN device-to-incumbent receiver with distance ≤ $d_{intermediate}$
        L(d) = Use WINNER II urban/suburban without clutter loss (section 4.2).
    ELSEIF RLAN device-to-incumbent receiver with distance ≥ *1.0* km
        IF $h_{RLAN,AGL} < h_a$
            L(d) = Use P2P ITM mean loss with ITU-R P.2108 mean clutter loss $L_{ITM}^{C}(d)$ (sections 4.1 and 4.4).
        ELSE
            L(d) = Use P2P ITM mean loss without clutter loss $L_{ITM}^{C}(d)$ (section 4.1).
        ENDIF
    ELSE
        IF $h_{RLAN,AGL} < h_a$
            Compute P2P ITM mean loss at *1* km & ITU-R P.2108 mean clutter $L_{ITM}^{C}(d = 1km)$ (sections 4.1, 4.4).
        ELSE
            Compute P2P ITM mean loss at *1* km without clutter loss $L_{ITM}^{C}(d = 1km)$ (sections 4.1).
        ENDIF
        Compute WINNER II loss at $d_{intermediate}$ (section 4.2).

L(d) = Interpolate between WINNER II at $d_{intermediate}$ and $L_{ITM}^{C}(d = 1km)$ using equation (1) (section 4.5.1) .

ENDIF

ELSE

IF LandCat==Deciduous

Set d_k=*0.05* and h_k=*15*.

ELSEIF LandCat==Coniferous

Set d_k=*0.05* and h_k=*20*.

ELSE

Set d_k=*0.07* and h_k=*5*.

ENDIF

Compute $a=\tan^{-1}((h_{receiver}-h_{RLAN,AGL})/1000d)$ and $b=\tan^{-1}((h_a-h_{RLAN,AGL})/1000d_k)$ (section 4.4).

IF "RLAN device-to-incumbent receiver distance $d > 10d_k$" and $a<b$ and $h_{RLAN,AGL} < h_a$

L(d) = Compute P2P ITM mean and ITU-R P.452 clutter loss $L_{ITM}^{C}(d)$ (sections 4.1 and 4.4).

ELSE

L(d) = Use P2P ITM without clutter $L_{ITM}^{C}(d)$ (section 4.1).

ENDIF

ENDIF

IF RLAN device is Indoor

Add ITU-R P2109 to propagation loss *L(d)* (section 4.3).

ENDIF

RETURN *L(d)*

END

6 Glossary

AFC: Automatic Frequency Controller
CBRS: Citizen Broadband Radio Services
IPC: Interference Protection Criteria
EHATA: Extended HATA
ITM: Irregular Terrain Model
P2P: Point-to-Point Mode
AP: Area Prediction Mode
DEM: Digital Elevation Model
km: Kilometers
DoD: Department of Defense
LoS: Line-of-Sight
NLoS: Non-Line-of-Sight
RLAN: Radio Local Access Network
USGS: United States Geological Survey
NLCD: National Landcover Database
NTIA: National Telecommunications and Information Administration
cdf: Cumulative Distribution Function
MRLC: Multi-resolution Land Characteristics
AMSL: Above Mean Sea Level
AGL: Above Ground Level
deg: Degree
dB: Decibel
FCC: Federal Communications Commission
REM: Radio Environment Map
BEL: Building Entry Loss
CONUS: Continental United States
3DEP: 3D Elevation Program
asec: Arc second
DB: Database
WGS: World Geodesic System
CONUS: Continental United States
WInnForum: Wireless Innovation Forum
ITU-R: International Telecommunications Union Radiocommunications
U.S.: United States

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